

EMI STANDARDS FOR WIRELESS VOICE AND DATA ON BOARD AIRCRAFT

Jay J. Ely and Truong X. Nguyen
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

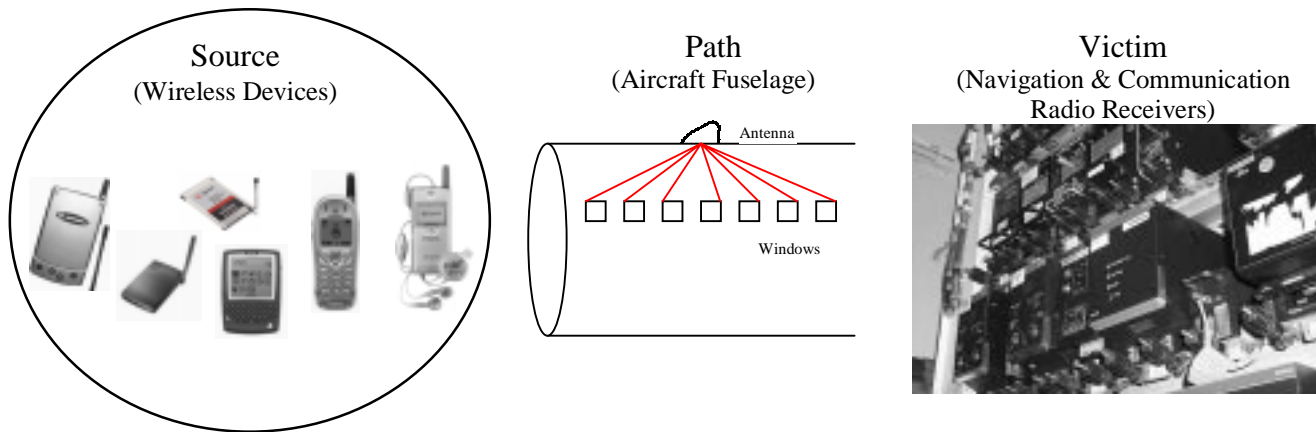


Figure 1: Overview of EMI situation between passenger carried wireless transmitters and aircraft communication and navigation radio receivers.

Abstract

The use of portable electronic devices (PEDs) on board aircraft continues to be an increasing source of misunderstanding between passengers and flight-crews, and consequently, an issue of controversy between wireless product manufacturers and air transport regulatory authorities. This conflict arises primarily because of the vastly different regulatory objectives between commercial product and airborne equipment standards for avoiding electromagnetic interference (EMI). This paper summarizes international regulatory limits and test processes for measuring spurious radiated emissions from commercially available PEDs, and compares them to international standards for airborne equipment. The goal is to provide insight for wireless product developers desiring to extend the freedom of their customers to use wireless products on-board aircraft, and to identify future product characteristics, test methods and technologies that may facilitate improved wireless freedom for airline passengers.

I. Introduction

Beginning with the introduction of the first commercially available transistor radios decades ago, numerous analyses have been conducted to address the potential for portable electronic device (PED) signals to interfere with airborne equipment. The most authoritative studies were performed by the RTCA in 1988 (RTCA DO-199 [1]) and 1996 (RTCA DO-233 [2]). These reports and subsequent publications commonly agree that the potential for interference is real, but infrequent [1-7]. The RTCA reports are the basis for current regulatory and advisory guidance from the Federal Aviation Administration (FAA), in the United States (US) [8,9]. Both RTCA reports identified the most likely source of EMI from PEDs to be their spurious radiated emissions into aircraft communication and navigation radio frequency bands. Both RTCA reports focused primarily upon the threat from unintentional transmitters, while recommending prohibition of intentional transmitters (citizens band, cellular, etc.) from operating during flight.

The explosive proliferation of wireless voice and data products, and the increasing reliance of travelers upon

them, creates a serious safety concern for airlines and the FAA. Wireless transmitters are increasingly being integrated into multifunction packages, often making it difficult for flight crews and passengers to identify them as intentional transmitters. Thus, the weakest aspect of the RTCA analyses, spurious radiated emissions of passenger wireless transmitters, is where there is the fastest emerging threat to critical aircraft navigation and communication radio frequency bands.

Most new-technology wireless transmitters incorporate spread-spectrum techniques and/or transmit-power-control for improved signal quality, range and capacity. These techniques tend to reduce the potential for interference between devices, as well as to nearby equipment. Because of this, it is reasonable to suspect that certain new-technology transmitters may be no more threatening to aircraft systems than unintentional transmitters (which passengers may legally use on board aircraft, with some restrictions).

Today's wireless technology customers expect their PEDs to be increasingly interoperable, reliable and safe to use, wherever they may be. As airplane passengers, they also have a very reasonable expectation that they will arrive safely and uneventfully at their destinations. NASA Langley Research Center has been working with the Federal Aviation Administration (FAA), airlines and universities to generate technical data, identify operational factors, and evaluate policy changes that may improve wireless accessibility aboard aircraft, without adversely impacting safety.

Figure 1 provides a general EMI description as it applies to this problem. Any EMI situation requires a source, path and susceptible victim. Aircraft path loss is defined as the radiated field attenuation between a PED, located in the passenger cabin of an aircraft, to the RF connection of a particular communication/navigation radio receiver, via its antenna. For passenger wireless on board aircraft, the most troublesome EMI situation occurs when a portable transmitter emits spurious signals into aircraft communication and navigation frequency bands. This paper will identify regulatory/industry standards for spurious radiated emissions from portable wireless transmitters, and compare them to airborne equipment standards. The goal is to provide insight for wireless product developers desiring to extend the freedom of their customers to use wireless products on-board aircraft, and to

identify future product characteristics, test methods and technologies that may facilitate improved wireless freedom for airline passengers.

II. Product Standards for Spurious Radiated Emissions

Commercial Products

In the US, the Federal Communications Commission (FCC) provides guidance for allowable signal emissions from consumer devices. These are published and available on the Internet, in the US Code of Federal Regulations (CFR), Title 47 "Telecommunication". Within Title 47, there are numerous "Parts" and "Sections" that address the full range of available product types. For example, to find guidance on spurious radiated emission limits for unlicensed, unintentional transmitters, FCC Part 15, Section 109 (or FCC 15.109) should be referenced. (Title 47 is implied by the "FCC" designation.) FCC 15.31 "Measurement Standards" specifies IEEE/ANSI C63.4 [10] as a measurement method for testing intentional and unintentional radiators. Table 1 identifies FCC regulations addressing spurious radiated emissions from several device types that passengers typically carry aboard aircraft.

In Europe, the International Electrotechnical Commission (IEC) provides guidance for allowable signal emissions from consumer devices. Measurement methods and test limits are provided in the IEC CISPR 22 publication. To promote free trade and facilitate technology transfer across international boundaries, the US and European Union (EU) have Mutual Recognition Agreements (MRA) which harmonize measurement processes and test limits for spurious radiated emissions. Most other nations recognize or adopt either the US or EU requirements.

In any case, these product standards address devices intended for use in residential, commercial, industrial or business environments. Both the US and EU further designate "Class A" and "Class B", where Class A devices are not intended for use in residential environments. Most consumer products are certified to the more rigorous Class B requirements. Table 1 provides a summary of spurious radiated emission limits for all common PEDs, including wireless voice and data transmitters (like wireless phones and LANs). It can readily be seen that there are numerous

different criteria for spurious radiated emissions from consumer devices. Some are defined in terms of electric field intensity ($\mu\text{V/m}$, $\text{dB}\mu\text{V/m}$), and some in terms of power (dBm). In addition, many of the guidelines utilize different processes for measuring maximum amplitude. (ie. Peak, Quasi-Peak, power, maximum peak output power, mean power). CISPR 22 states that “the significance of the limits shall be that on a statistical basis at least 80% of the mass-produced equipment comply with the limits with at least 80% confidence.” Clearly, there is much room for uncertainty in quantifying emissions from consumer products.

Standard	Applicability	Limits
FCC 15.109 Class B	Unlicensed Unintentional Transmitters	88 - 216 MHz: $150\mu\text{V/m}$ 216 - 960 MHz: $200\mu\text{V/m}$ > 960 MHz: $500\mu\text{V/m}$ (All meas. @ 3 meters)
FCC 15.209	Unlicensed Intentional Transmitters	88 - 216 MHz: $150\mu\text{V/m}$ 216 - 960 MHz: $200\mu\text{V/m}$ > 960 MHz: $500\mu\text{V/m}$ (All meas. @ 3 meters)
FCC 22.917	Cellular Wireless Phones	90 kHz or more from carrier frequency: $43 + 10\log(P)$ dB
FCC 24.238	PCS Wireless Phones	Outside licensee frequency block: $43 + 10\log(P)$ dB
FCC 95.857	Family Radio Service	Outside assigned frequency segment more than 1250 kHz: $43 + 10\log(P)$ dB
IEC CISPR 22	Information. Tech. Equip., Unlicensed Transmitters	30–230 MHz: $30\text{ dB}\mu\text{V/m}$ 230–1000 MHz: $37\text{ dB}\mu\text{V/m}$ (All meas. @ 10 meters)
GSM 11.10	GSM Wireless Phones	30 - 1000 MHz: -36dBm 1 - 4 GHz: -30dBm 1717 - 1785 MHz: -36dBm (for DCS1800)
Bluetooth 1.1	Bluetooth Radio Specification	30 - 1000 MHz: -36dBm 1 - 12.75 GHz: -30dBm 1.8 - 1.9 GHz: -47dBm 5.15 - 5.3 GHz: -47dBm

Table 1: Summary of certification standards for commercial product limits for spurious radiated emissions.

Airborne Equipment (Civil)

In the US, the FAA provides guidance for allowable signal emissions from aircraft electronic systems. These

are not directly stated in the US CFR (as with the FCC limits for consumer devices). Instead, 14CFR91.21 states that PEDs “may be used if the aircraft operator has determined that they will not cause interference with the navigation or communication system of the aircraft on which it is to be used”[8]. Further guidance is provided by Advisory Circular 91.21-1A, which states that designing and testing PEDs in accordance to RTCA/DO-160D [11] may constitute one acceptable method allowing their operation on board aircraft [9].

RTCA/DO-160D, Section 21 contains measurement procedures and test limits to determine whether electronic equipment emits excessive RF signals when installed in a particular location. The requirements are “harmonized” with EUROCAE ED-14 [12], and therefore technically identical, and acceptable to Europe’s Joint Aviation Authorities (JAA). Various equipment categories are defined in terms of location and separation between the equipment and aircraft radio antennas. The two categories applicable to potential PED locations are as follows:

Category M: Equipment and wiring located in passenger cabin and cockpit, not directly in view of aircraft radio receiver antennas.

Category H: Equipment and wiring located directly in view of aircraft radio receiver antennas.

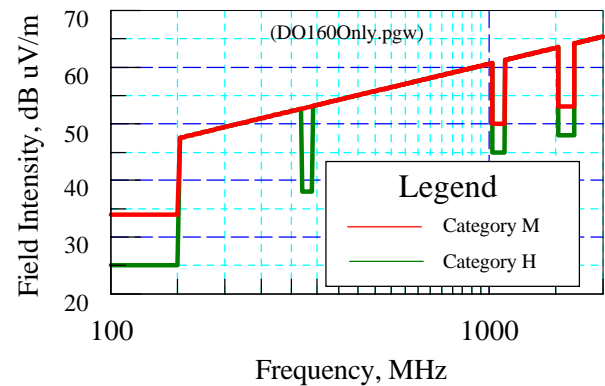


Figure 2: Spurious radiated emissions limits, at 1 meter distance, for airborne equipment, RTCA/DO-160D, Section 21.

While Category M appears to most directly address the situation of PEDs in the passenger cabin, the fact that such devices are mobile allow their positioning in optimal

coupling locations within the passenger cabin. It is not uncommon for aircraft to have nav/com antennas placed less than 2 meters away from windows and door exits. Figure 2 shows the emissions limits for RTCA/DO-160D Category M and H. It should be noted that equipment installed in aircraft designs certified prior to 1997 may not be required to meet RTCA/DO-160D levels, however the RTCA/DO-160D levels are given here as an indication of the most recent assessment of safe limits for airborne equipment. It is the author's belief that the DO-160D Category H limits are the most applicable for ensuring non-interference with aircraft radios.

In summary, it is important to note that the goals and intentions behind commercial and airborne equipment standards are entirely different. Commercial product standards are mostly concerned with interoperability issues, whereas airborne equipment standards are primarily concerned with flight safety. Because the limits are specified differently ($\mu\text{V/m}$, $\text{dB}\mu\text{V/m}$, dBm), additional analysis is required to address their comparability.

III. Conversion Between V/m , $\mu\text{V/m}$, $\text{dB}\mu\text{V/m}$ and dBm for Emission Standards

FCC Part 15 and IEC CISPR22 provide spurious radiated emission limits in terms of Electric Field Intensity (E) at a given distance. The basic units of E are Volts/meter (V/m), however because the radiated emission limits are so low, units of either $\mu\text{V/m}$ or $\text{dB}\mu\text{V/m}$ are specified as follows:

$$\mu\text{V/m} = \text{V/m} \cdot 10^{-6} \quad (1)$$

$$\text{dB}\mu\text{V/m} = 20\log[\text{V/m} \cdot 10^{-6}] \quad (2)$$

Limits for spurious radiated emissions from intentional transmitters are usually specified as maximum output power (P) levels at the antenna connector. The basic units of P are Watts, however, again because the radiated emission limits are low, units of dB relative to 1 milliwatt (dBm) are typically specified as follows:

$$\text{dBm} = 10\log[P/0.001 \text{ Watt}] \quad (3)$$

It is possible to convert between field intensity and radiated power, if specific boundary conditions are

specified. For example, if a “free space” environment is assumed (ie. no reflections or electromagnetic variation in properties from nearby environment), Equation (4) can be used to compare E and P. See Figure 3.

$$P = [E^2 \cdot 4\pi R^2 \cdot G]/120\pi \quad (4)$$

where

P= Power applied at antenna connector. (Watts)

E= Electric field Intensity as specified in a plane a distance R from the antenna. (Volts/meter)

R= Distance between point at which Electric Field Intensity is measured/computed and point of antenna radiation. (meters)

G= Directive Gain of antenna over an isotropic antenna.

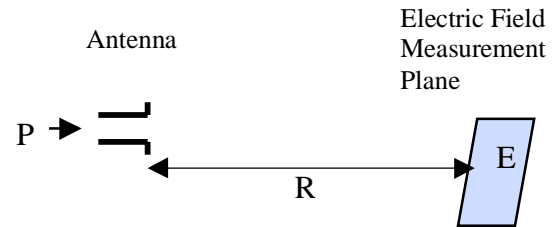


Figure 3: Diagram for relationship between applied power (P) to an efficient antenna to the electric field intensity (E) at some distance (R) away.

Expected Maximum Directivity

Equation (4) addresses the E and P relationship, at some distance, for an *antenna*. It is important to note that the Table 1 limits are specified for unintentional spurious radiated emissions, where the antenna is inadvertent, with unknown gain characteristics. It is therefore necessary to make assumptions about the directive Gain characteristics of various PEDs. Antenna Gain is defined the product of Directivity and Efficiency:

$$G = eD \quad (5)$$

e = Efficiency.

D = Directivity

Directivity is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions [13]. Efficiency (e) varies from 0 to 1, and accounts for mismatch and loss.

If the emission limits from Table 1, specified in P, are to be converted to E (at some distance) the out-of-band efficiency and Directivity of the antenna needs to be estimated. Unfortunately, specific antenna designs are not mandated by regulatory standards. Another approach is to convert emission limits specified in E, at some distance, to P. This approach provides the actual radiated power, which allows us to assume 100% efficiency, even from an unintentional transmitter.

To estimate D for unintentional transmitters, a statistical theory developed to quantify uncertainties for radiated emission measurements performed in anechoic chambers can be applied [14]. For a device with maximum overall dimension of 15 cm (typical wireless phone), the expected maximum D can be estimated when sampling over one rotational plane. See Figure 4. A one-rotational plane spurious radiated emission measurement represents standard practice according to IEEE/ANSI C63.4 and CISPR22. If the device maximum overall dimension were to increase beyond 15 cm, the breakpoint for increasing directivity would occur at a lower frequency.

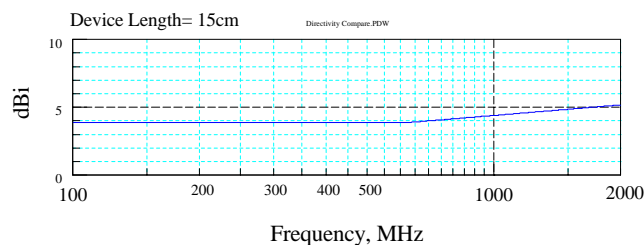


Figure 4: Expected maximum Directivity over 1 rotational plane (referenced to isotropic radiator), using statistical estimates provided by [14].

IV. Commercial Product Standards Comparison to Airborne Equipment Test Limits

Applying the conversion equations and directivity estimates of Section III to the spurious radiated emission limits of Section II, commercial product standards are directly compared to airborne equipment qualification standards in Figure 5.

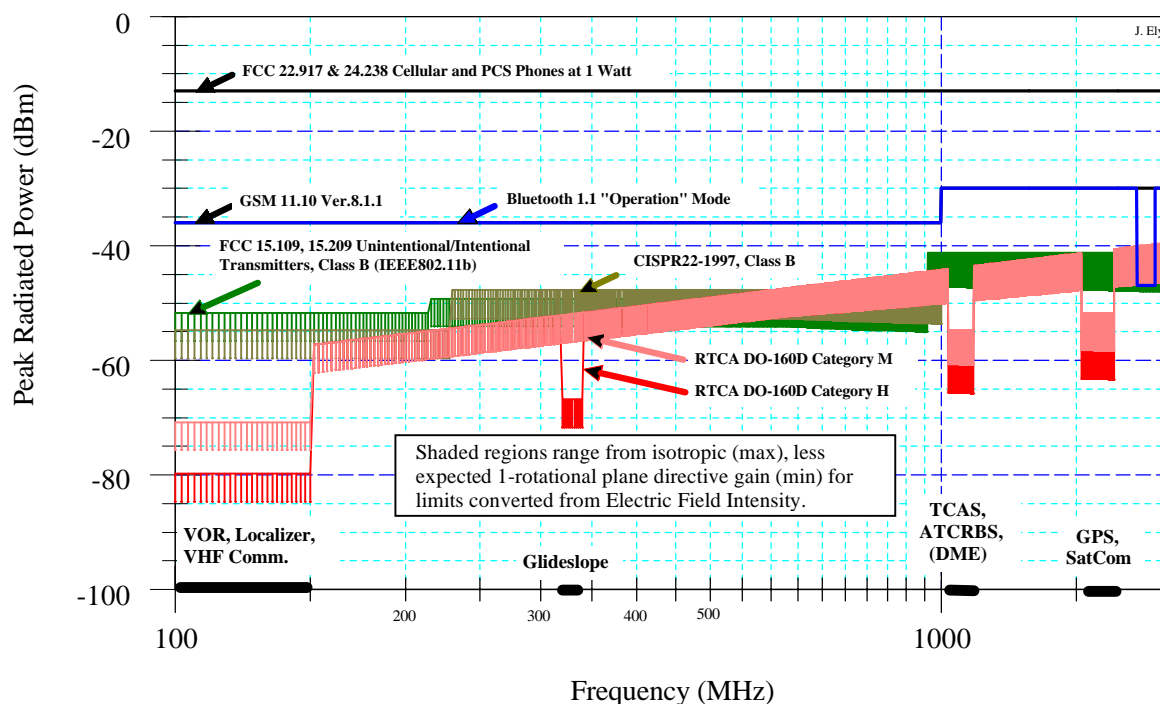


Figure 5: Comparison of spurious radiated emission limits from consumer products versus RTCA/DO-160 qualification limits for airborne equipment. Aircraft radio frequency bands are shown along the bottom frequency scale.

In Figure 5, all limits were normalized to radiated power (P, in dBm). This allows direct application of aircraft path loss and aircraft radio receiver interference level data. RTCA/DO-233 [2] applied this approach for unintentional transmitters. The figure clearly shows a large difference between allowable limits for spurious radiated emissions from consumer products versus airborne equipment. The difference becomes alarming when intentional transmitters such as cellular and PCS wireless phones are considered. Fortunately, the built-in antennas of most transmitters will reject most signals from radiating outside the intended frequency band. Device measurements at NASA Langley Research Center have shown that typical wireless voice and data products radiate spurious signals in aircraft radio bands at levels far below commercial standards. While this is comforting, the best approach for PED usage policy must rely on “allowable”, rather than “typical” emissions levels.

V. Bringing Wireless On-Board- What Needs to Be Done?

The preceding analysis demonstrates that commercial spurious radiated emission standards are not intended to provide protection to aircraft communication and navigation radio frequency bands. In order to bring the promise of new wireless freedom to tomorrow’s airline passengers, it will be necessary to modify existing regulatory policies and develop technology solutions. The RTCA PED studies recommended special classes of “airworthy” products and/or more rigorous government standards for all products. This author also recommends early adoption of more rigorous industry standards for emerging technology (ie. 3G & Beyond), and development of new technologies to facilitate the regulatory process. Technology solutions could include systems to detect unauthorized devices, schemes for remote power control of passenger transmitters, and documentation of common product failure modes that could result in increased radiated emissions in aircraft radio frequency bands.

VI. Acknowledgements

This work funded by NASA’s Aviation Safety Program and the FAA by a NASA/FAA Interagency Agreement.

VII. References:

- [1] RTCA/DO-199, “Potential Interference to Aircraft Electronic Equipment from Devices Carried Aboard”, September 16, 1988.
- [2] RTCA/DO-233, “Portable Electronic Devices Carried on Board Aircraft”, August 20, 1996.
- [3] Perry, T., Geppert, L., “Do Portable Electronics Endanger Flight? The Evidence Mounts”, IEEE Spectrum Magazine, September, 1996.
- [4] Helfrick, A., “Avionics & Portable Electronics: Trouble in the Air?”, Avionics News Magazine, September 1996.
- [5] Ladkin, Peter B., “Electromagnetic Interference with Aircraft Systems: why worry?”, Article RVS-J-97-03, University of Bielefeld, October 20, 1997.
- [6] Donham, Bruce, “Electromagnetic Interference from Passenger-Carried Portable Electronic Devices”, Boeing Aero Magazine No. 10, March, 2000.
- [7] Ross, Elden, “Personal Electronic Devices and Their Interference With Aircraft Systems”, NASA/CR-2001-210866, June 2001.
- [8] 14CFR 91.21, “Portable Electronic Devices”, US Code of Federal Regulations, Federal Register dated February 1, 2002.
- [9] AC 91.21-1a (FAA Advisory Circular), “Use of Portable Electronic Devices Aboard Aircraft”, 10/02/2000.
- [10] ANSI C63.4-2000, “Interim Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz”, Published by the IEEE, December 8, 2000.
- [11] RTCA/DO-160, “Environmental Conditions and Test Procedures for Airborne Equipment”, July 29, 1997.
- [12] Eurocae ED-14, “Environmental conditions and Test Procedures for Airborne Equipment, July, 1997.
- [13] ANSI/IEEE Std. 100-1988, “IEEE Standard Dictionary of Electrical and Electronics Terms”, Fourth Edition, July 8, 1988.
- [14] Koepke, Hill, Ladbury, “Directivity of the Test Device in EMC Measurements”, 2000 IEEE International Symposium on Electromagnetic Compatibility, August 21-25, 2000.